Reply to Ali & Aitchison's comment on 'Restoration of Cenozoic deformation in Asia, and the size of Greater India'

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[1] In our recent paper [*van Hinsbergen et al.*, 2011a], we provide a kinematic restoration of Cenozoic deformation in Asia based on the currently available kinematic estimates on fault zones and fold-thrust belts in Tibet, the Pamir, the Tien Shan, Mongolia, Siberia and Indochina. Our reconstruction suggests that approximately 1050 km (in the Pamir) to 600 km (in eastern Tibet) of India-Asia convergence was accommodated by intraAsian shortening in the last ~50 Ma. By comparing this reconstruction with the respective positions of India and Asia constrained by the Eurasia-North America-Africa-India plate circuit (using model A of *van Hinsbergen et al.* [2011b]), we explored the implications for the size for Greater India as a function of collision age, whereby we define Greater India as 'the area of lithosphere consumed by northward subduction beneath the Asian margin since collision of the Tibetan Himalaya with Asia'. Importantly, we do not a priori define that all that lithosphere must be continental in nature. Our reconstruction demonstrated that if collision started by 50 Ma, Greater India *at the time of initial collision* must have been up to 2600 km wide. Such a 50 Ma collision age follows from the timing of the first arrival of Asia-derived detritus in the Tibetan Himalaya [*Najman et al.*, 2010; *Wang et al.*, 2011; *Hu et al.*, 2012] and the overlap of paleomagnetically determined paleolatitudes from the former southern margin of Asia (the Lhasa terrane) [e.g., *Dupont-Nivet et al.*, 2010a; *Lippert et al.*, 2011], with those from the Tibetan Himalaya [*Patzelt et al.*, 1996; *Yi et al.*, 2011]. Such a large N-S width of Greater India in Late Cretaceous and Paleocene time is consistent with the high-quality paleomagnetic data from Tibetan Himalayan rocks of *Patzelt et al.* [1996], shown to have undergone negligible inclination shallowing due to compaction by *Dupont-Nivet et al.* [2010b], and recently corroborated by *Yi et al.* [2011]: When compared to high-quality paleomagnetic poles from India, those paleomagnetic data demonstrate a N-S separation between the Tibetan Himalaya and the Indian craton of 22.0 ± 3.0° (2442 ± 333 km) at ~68 Ma [*van Hinsbergen et al.*, 2012].

[2] In their comment, *Ali and Aitchison* [2012] question the large size of Greater India at the time of collision because of strong evidence for a small (<1000 km) Greater India in Early Cretaceous and older time. We note that they do not question any of the data or interpretations constraining the amount of intraAsian shortening, which is central to *van Hinsbergen et al.* [2011a]. Rather, they question the 50 Ma collision age, and prefer a collision age of 34 Ma instead, in part based on selected paleomagnetic poles from India and Asia (instead of a plate circuit and disregarding paleomagnetic data from the Lhasa terrane and the Tibetan Himalaya), assuming negligible to no intraAsian deformation since collision, and a limited (<1000 km) size of Greater India before collision [*Aitchison et al.*, 2007].

[3] We wholeheartedly agree that the N-S size of Greater India in Early Cretaceous time was modest, as put forward by *Ali and Aitchison* [2005; 2012]. In addition to the evidence they summarize, paleomagnetic data from ~120 Ma rocks in the Tibetan Himalaya of *Klootwijk and Bingham* [1980] demonstrate that Greater India at that time was not larger than ~900 km (see analysis in *van Hinsbergen et al.* [2012]). As such, we acknowledge that the size of Greater India at 140 Ma as shown in Figure 1a of *van Hinsbergen et al.* [2011b] is incorrect. The paleomagnetic data put forward from the Upper Cretaceous and Paleocene of the Tibetan Himalaya by *Patzelt et al.* [1996] and *Yi et al.* [2011] in combination with the pole from the Lower Cretaceous of *Klootwijk and Bingham* [1980] thus demonstrate that the size of Greater India increased significantly

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(24.1 ± 6.3°, or 2675 ± 699 km in a N-S direction, see *van Hinsbergen et al.* [2012]) between ∼120 and 70 Ma. In other words, Greater India underwent major N-S extension in Cretaceous time. *Van Hinsbergen et al.* [2012] argued that this extension led to the rifting of a microcontinent that contained the Tibetan Himalaya away from the Indian craton, opening a largely oceanic 'Greater India Basin' between the Tibetan Himalaya and the Indian craton. Such significant rifting is consistent with well-documented alkali-basaltic volcanic and volcaniclastic sediments from the Lower Cretaceous (140–100 Ma) of the Tibetan Himalaya [*Gaetani and Garzanti*, 1991; *Garzanti*, 1999; *Jadoul et al.*, 1998; *Zhu et al.*, 2008; *Hu et al.*, 2010]. The large size of Greater India as shown in Figures 1b–1d of *van Hinsbergen et al.* [2011b] and Figures 4 and 5 of *van Hinsbergen et al.* [2011a] is thus supported by paleomagnetic data.

[4] For reasons unknown, *Ali and Aitchison* [2006; 2012] and *Aitchison et al.* [2007; 2011] ignore the high-quality paleomagnetic evidence presented by *Patzelt et al.* [1996] (and *Yi et al.* [2011]) for a large Greater India since ∼70 Ma. They also ignore paleomagnetic data from the Lhasa terrane, as presented by e.g., *Chen et al.* [2010], *Dupont-Nivet et al.* [2010a], and *Liebke et al.* [2010]. As a consequence, their paleomagnetic argument that the collision between the Tibetan Himalaya and the Lhasa terrane must be as young as 34 Ma is flawed.

[5] In summary, the arguments put forward by *Ali and Aitchison* [2012] for a modest size of Greater India at and before 130 Ma are in our view correct. Their conclusion that this evidence disproves the large size of Greater India by Late Cretaceous time, however, neglects robust paleomagnetic data showing that the size of Greater India increased significantly after the Early Cretaceous and before collision of the Tibetan Himalaya with Asia [*van Hinsbergen et al.*, 2012], and is hence incorrect.

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